WHAT IS CLAIMED IS:

1.   A vehicle control method comprising:

calculating a physical quantity which relates to a tire force of each wheel and optimizes an effective road friction of each wheel, based on a target resultant force to be applied to a vehicle body in order to obtain vehicle body motion that a driver desires, and a constraint including as parameters a magnitude of a critical friction circle of each wheel;

calculating, based on the calculated physical quantity relating to the tire force of each wheel, a first control variable for controlling at least one of braking force and driving force of each wheel, or a second control variable for controlling the first control variable and a steering angle of each wheel; and

controlling (A) the at least one of braking force and driving force of each wheel based on the first control variable, or controlling (A) the at least one of braking force and driving force of each wheel and (B) the steering angle of each wheel based on the first and second control variables.

2.   The method of claim 1, wherein the constraint is represented by a formula indicating that no resultant force is generated in a direction orthogonal to a direction of the target resultant force, and a formula indicating that a moment around the center of gravity of the vehicle is equal to a desired moment.

3.   The method of claim 2, wherein the constraint is represented by formulae, the number of which is less than that of wheels, or a linearized formula.

4.   The method of claim 2, wherein:

the target resultant force is represented by a secondary performance function including the magnitude of the critical friction circle of each wheel and the physical quantity relating to the tire force of each wheel; and

a physical quantity relating to the tire force of each wheel, which physical quantity satisfies a first approximation formula of a formula defining the constraint and optimizes the secondary performance function, is calculated as the physical quantity which relates to the tire force of each wheel and optimizes the effective road friction of each wheel.

5.   The method of claim 2, wherein:

the target resultant force is represented by a secondary performance function including the magnitude of the critical friction circle of each wheel and the physical quantity relating to the tire force of each wheel; and

a physical quantity relating to the tire force of each wheel, which physical quantity satisfies a first approximation formula of a formula defining the constraint and optimizes the secondary performance function, is calculated as an initial value;

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the formula defining the constraint is linearized by using the calculated initial value;

a physical quantity relating to the tire force of each wheel, which physical quantity satisfies the linearized formula of the constraint and optimizes the secondary performance function, is calculated as an approximate solution; and

the physical quantity which relates to the tire force of each wheel and optimizes the effective road friction of each wheel is calculated by using the calculated approximate solution as the initial value to repeat the linearization of the formula defining the constraint and the calculation of the approximate solution.

6.   The method of claim 5, wherein the formula defining the constraint is linearized by Taylor expansion around the initial value or the approximate solution.

7.   The method of claim 1, wherein:

the physical quantity relating to the tire force is a direction of the tire force; and

the effective road friction of each wheel, the calculated direction of the tire force of each wheel, and the magnitude of the critical friction circle of each wheel are used to calculate a slip angle based on a brush model, and the calculated slip angle is used to calculate the second control variable based on a vehicle motion model.

8.   The method of claim 1, wherein the magnitude of the critical friction circle of each wheel is determined based on an estimate or a virtual value of μ of each wheel and a load of each wheel.

9.   The method of claim 1, wherein:

the physical quantity relating to the tire force is a direction of the tire force; and

the direction of the tire force which optimizes the effective road friction of each wheel is one of a direction of the tire force which uniformly minimizes the effective road friction of each wheel, a direction of the tire force which makes the effective road friction of a front wheel differ from that of a rear wheel, and a direction of the tire force which makes a magnitude of the tire force of each wheel proportional to the load of the wheel.

10.   The method of claim 9, further comprising using, for a wheel having a small μ, the magnitude of the critical friction circle as the magnitude of the tire force, and using, for a wheel having a large μ, the magnitude of the tire force which minimizes the effective road friction, when the magnitude of the tire force proportional to the load of the wheel cannot be obtained because each wheel has a different μ with respect to a road surface.

11.   The method of claim 1, wherein the steering angle is controlled so as to be the same for the right and left wheels.

12.   The method of claim 1, wherein the effective road friction is represented by a magnitude of the target resultant force relative to a magnitude of a critical resultant force obtained from the magnitude of the critical friction circle of each wheel.

13.   The method of claim 7, wherein the direction of the tire force which is generated by each wheel is defined as a value, that is the sum of products, which are calculated for all other wheels, of a distance from the position of an object wheel to the position of the other wheel in the direction of the resultant force, and the magnitude of the critical friction circle of the other wheel, with the direction of the resultant force acting on the vehicle body as the resultant force of the tire forces of the respective wheels being used as a reference.

14.   A vehicle control apparatus comprising:

target resultant force calculating means for calculating a target resultant force to be applied to a vehicle body in order to obtain a vehicle body motion that a driver desires;

critical friction circle estimating means for estimating a magnitude of a critical friction circle of each wheel;

tire force calculating means for calculating a physical quantity which relates to a tire force of each wheel and optimizes an effective road friction of each wheel, based on the target resultant force and a

constraint including as parameters the magnitude of the critical friction circle of each wheel;

control variable calculating means for calculating, based on the calculated physical quantity relating to the tire force of each wheel, a first control variable for controlling at least one of braking force and driving force of each wheel, or a second control variable for controlling the first control variable and a steering angle of each wheel; and

control means for controlling (A) the at least one of braking force and driving force of each wheel based on the first control variable, or controlling (A) the at least one of braking force and driving force of each wheel and (B) the steering angle of each wheel based on the first and second control variables.

15.   The apparatus of claim 14, wherein the constraint is represented by a formula indicating that no resultant force is generated in a direction orthogonal to a direction of the target resultant force, and a formula indicating that a moment around the center of gravity of the vehicle is equal to a desired moment.

16.   The apparatus of claim 15, wherein the constraint is represented by formulae, the number of which is less than that of wheels, or a linearized formula.

17.   The apparatus of claim 15, wherein:

the target resultant force is represented by a secondary performance function including the magnitude of the critical friction circle of each wheel and the physical quantity relating to the tire force of each wheel; and

the tire force calculating means calculates a physical quantity relating to the tire force of each wheel, which physical quantity satisfies a first approximation formula of a formula defining the constraint and optimizes the secondary performance function, as the physical quantity which relates to the tire force of each wheel and optimizes the effective road friction of each wheel.

18.   The apparatus of claim 15, wherein:

the target resultant force is represented by a secondary performance function including the magnitude of the critical friction circle of each wheel and the physical quantity relating to the tire force of each wheel; and

the tire force calculating means calculates as an initial value a physical quantity relating to the tire force of each wheel, which physical quantity satisfies a first approximation formula of a formula defining the constraint and optimizes the secondary performance function, linearizes the formula defining the constraint by using the calculated initial value, calculates as an approximate solution a physical quantity relating to the tire force of each wheel, which physical quantity satisfies the linearized formula of the constraint and optimizes the secondary performance function, and calculates the

physical quantity which relates to the tire force of each wheel and optimizes the effective road friction of each wheel by using the calculated approximate solution as the initial value to repeat the linearization of the formula defining the constraint and the calculation of the approximate solution.

19.   The apparatus of claim 18, wherein the tire force calculating means linearizes the formula defining the constraint by Taylor expansion around the initial value or the approximate solution.

20.   The apparatus of claim 14, wherein:

the physical quantity relating to the tire force is a direction of the tire force; and

the control variable calculating means calculates a slip angle based on a brush model by using the effective road friction of each wheel, the calculated direction of the tire force of each wheel, and the magnitude of the critical friction circle of each wheel, and calculates the second control variable based on a vehicle motion model by using the calculated slip angle.

21.   The apparatus of claim 14, wherein the critical friction circle estimating means determines the magnitude of the critical friction circle of each wheel based on an estimate or a virtual value of μ of each wheel and a load of each wheel.

22.   The apparatus of claim 14, wherein:

the physical quantity relating to the tire force is a direction of the tire force; and

the direction of the tire force which optimizes the effective road friction of each wheel is one of a direction of the tire force which uniformly minimizes the effective road friction of each wheel, a direction of the tire force which makes the effective road friction of a front wheel differ from that of a rear wheel, and a direction of the tire force which makes the magnitude of the tire force of each wheel proportional to a load of the wheel.

23.   The apparatus of claim 22, wherein, when the magnitude of the tire force proportional to the load of the wheel cannot be obtained because each wheel has a different μ with respect to a road surface, the magnitude of the critical friction circle is used as the magnitude of the tire force for a wheel having a small μ, and the magnitude of the tire force which minimizes the effective road friction is used for a wheel having a large μ.

24.   The apparatus of claim 14, wherein the control means controls the steering angle so that the steering angle is the same for the right and left wheels.

25.   The apparatus of claim 14, wherein the effective road friction is represented by a magnitude of the target resultant force relative to

a magnitude of a critical resultant force obtained from the magnitude of the critical friction circle of each wheel.

26.   The apparatus of claim 20, wherein the direction of the tire force which is generated by each wheel is defined as a value, that is a sum of products, which are calculated for all other wheels, of a distance from the position of an object wheel to the position of the other wheel in the direction of the resultant force, and the magnitude of the critical friction circle of the other wheel, with the direction of the resultant force acting on the vehicle body as the resultant force of the tire forces of the respective wheels being used as a reference.

27.   A vehicle control apparatus comprising:

target resultant force calculating means for calculating a target resultant force to be applied to a vehicle body in order to obtain a vehicle body motion that a driver desires;

critical friction circle estimating means for estimating a magnitude of a critical friction circle of each wheel;

critical resultant force estimating means for estimating a critical resultant force based on the magnitude of the critical friction circle of each wheel estimated by the critical friction circle estimating means;

effective road friction setting means for setting a ratio of the target resultant force to the critical resultant force as an effective road friction;

magnitude of tire force setting means for setting a magnitude of a tire force used at each wheel, which tire force is obtained by multiplying the magnitude of the critical friction circle of each wheel by the effective road friction;

direction of tire force setting means for setting a direction of the tire force generated by each wheel based on a value, that is a sum of products, which are calculated for all other wheels, of a distance from the position of an object wheel to the position of the other wheel in a direction of the resultant force, and the magnitude of the critical friction circle of the other wheel, with the direction of the resultant force acting on the vehicle body as the resultant force generated by the tire force of each wheel being used as a reference; and

control means for controlling a steering angle of each wheel and at least one of braking force and driving force of each wheel based on the magnitude and direction of the tire force which have been set.

28.   The apparatus of claim 27, wherein the control means comprises:

means for calculating, based on the calculated direction and magnitude of the tire force of each wheel, a first control variable for controlling at least one of braking force and driving force of each wheel, or a second control variable for controlling the first control variable and the steering angle of each wheel; and

means for controlling (A) the at least one of braking force and driving force of each wheel based on the first control variable, or

controlling (A) the at least one of braking force and driving force of each wheel and (B) the steering angle of each wheel based on the first and second control variables.